AT THE ENTERPRISES AND INSTITUTES

UDC 666.295:535.6

CONTROL OF COLOR PARAMETERS IN CERAMIC TILES

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Translated from Steklo i Keramika, No. 12, pp. 23 – 26, December, 2004.

Color differences found in ceramic tiles are analyzed with respect to pattern variability in time with increasing wear of the printing screen. It is found that the degree of screen wear is a critical factor in producing color shade differences. The results of an instrumental analysis of color parameters of ceramic tiles are compared with estimates of the same parameters given by consumers. A substantial discrepancy between the perception of the expert group regarding ceramic tile colors and the data of instrumental analysis is observed.

There is a general trend to expand the color range of ceramic facing tiles, which makes the problem of objective control of their color characteristics topical. The current standards (GOST 27180–86, GOST 6141–91, EN 98, EN 159, EN 163, EN 176, EN 178, etc.) prescribe only technical, thermophysical, and geometrical parameters, as well as defects on the facing surface of ceramic tiles. The colorimetric parameters are controlled visually in sorting finished tiles on a conveyor belt by comparing them with reference standards. As in any subjective control method, this method does not provide objective information on the colorimetric parameters of ceramic tiles.

Consequently, apart from comparison with reference standards whose surface properties differ and whose colors may change with time, one needs to measure the color of a tile using objective control methods, in particular spectrometric curves. The obtained curves can serve as a characteristic of tint, which is expressed via the wavelength corresponding to the curve maximum (the color tone), via the white color part that needs to be mixed with monochromatic light corresponding to the maximum (color saturation), and via color intensity (brightness). However, using this method it is necessary to take into account the change in the observer's eye sensitivity in order to determine the effect of light with a particular wavelength on the color of the sample. In other words, the estimate of a color may differ from the estimate of the same color in a specific situation. Therefore, the results of laboratory studies of color characteristics cannot serves as the only foundation for the estimate of its chromatic composition [1 – 3].

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At present, theoretical and experimental studies on tolerances for color differences differentiated by eye in ceramic tiles are absent, which makes it expedient to implement up-to-date objective colorimetric methods based on easy-to-use equipment for commercial estimate of finished products.

The purpose of the present paper is to analyze color differences in ceramic tiles regarding the variability of the pattern with time caused by wear of the printing screen and to compare the results of instrumental analysis of color characteristics of tiles with estimates given by consumers.

We investigated a batch of "Bologna" ceramic wall tiles of size 200×250 mm produced by the Velor JSC (city of Orel). The decoration was performed by silk-screen printing using three different pastes (gray, green, and pink). To be decorated, a tile with a white glaze coating consecutively passes through three screens with different patterns. Each screen applies paste of a certain color; the first screen applies the gray color, the second one — the green paste, and the third one — the pink paste. The number of tiles in the experimental batch was limited by the wear of printing screens.

The colorimetric characteristics were studied with a Pulsar spectrocolorimeter (each 500th tile). Since the pattern on the tile is heterogeneous, the colorimetric parameters were measured according to the following method. A mask of blackened metal foil 0.05 mm thick was made with uniformly distributed openings whose diameter corresponded to the light beam diameter of the spectrocolorimeter. The mask was applied to a ceramic tile and the colorimetric parameters of the pattern corresponding to each opening in the mask were determined. The obtained data were averaged for each ceramic tile investigated.

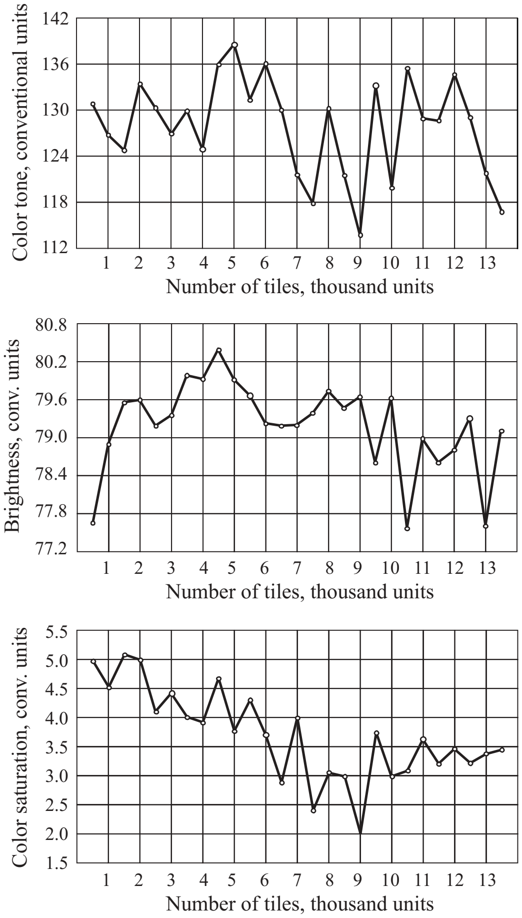

Fig. 1. Variation of color tone, brightness, and saturation in ceramic tiles.

Color tone, brightness, and color saturation were accepted as criteria permitting one to estimate the differences in color shades of the tile [4, 5]. Color differences in tiles were analyzed, first with respect to the variability of the pattern itself, and second with respect to pattern variation in time with increasing screen wear (the wear of the screen is not the only factor producing different hues in ceramic tiles).

The results of the colorimetric studies are shown in Fig. 1. The analysis established the variation of the color coordinates with time due to the pattern texture variability and identified several zones in which the changes in color parameters are the most significant.

The analysis of the pattern variability with time identified a significant spread in color tone values. The color tone differences increase with increasing wear of the printing screen (starting approximately with the 6000th tile). The color tone variation coefficient calculated in accordance with the data in [6] was equal to 5%.

The lowest brightness was observed in the initial printing phase (the first 500 tiles). In the next phase (500 – 1500 tiles) the brightness index sharply increases. Next (2000 – 5500 tiles), the brightness generally increases, but its fluctuations grow. In the interval of 6000 – 13,000 tiles a decrease in brightness was observed, while the fluctuation amplitude of this parameter kept increasing. It should be noted that brightness was the most uniform of the parameters investigated. The variation coefficient for this parameter was approximately 0.89%.

As for color saturation, generally within the interval from 1 to 9000 tiles this parameter decreases with time. The spread in values grows with a growing extent of wear of the printing screen (starting with approximately 3000 tiles). Then in the inertial of 9500 – 13,000 tiles a certain increase in color saturation is observed, although its values do not reach the original value. The variation coefficient for this parameters is 21%.

The obtained data on pattern variability with time can be interpreted as follows. In the first stage of the contact of the screen with the slice and the tile, the polymer filaments of the screen undergo plastic deformation. The filament section acquires an oval shape, which decrease the effective section of the screen cells (Fig. 2) and, in its turn, decreases the amount of paste squeezed through the screen and, consequently, decreases color saturation and increases the brightness of the pattern produced.

In the second phase of screen service, the effective section of the screen cells increases as a consequence of the abrasive effect of paste on screen filaments, which raises the amount of paste squeezed through; consequently, the brightness decreases and the saturation of the pattern increases.

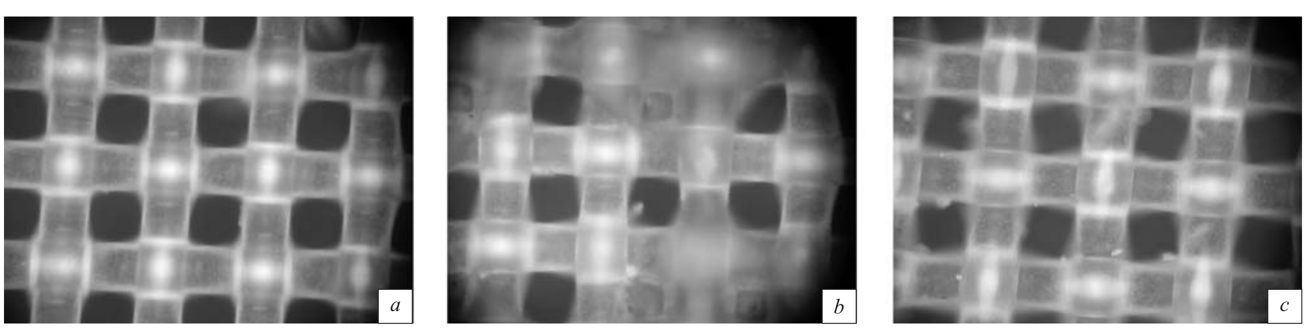

Fig. 2. Microphotos of printing screen (× 100) before service (*a*), at initial (*b*) and final (*c*) stages of printing.

TABLE 1

Expert	Rank of ceramic tile samples																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	18	10	11	15	17	13	14	12	16	9	8	23	22	20	1	2	4	21	7	19	6	5	3
2	7	6	8	15	9	2	17	10	18	11	12	21	19	22	4	13	20	3	1	16	23	14	5
3	20	19	18	17	16	14	15	13	12	11	10	21	22	8	7	9	6	5	4	3	23	2	1
4	16	15	14	19	13	8	9	17	10	12	7	20	22	4	3	5	11	18	2	23	21	1	6
5	20	19	18	17	16	15	14	13	12	11	10	21	22	8	7	9	6	5	4	3	23	2	1
6	15	14	20	21	12	11	13	10	9	8	7	23	17	19	5	16	18	4	3	2	22	1	6
7	23	22	18	17	16	15	14	12	13	11	10	19	21	9	8	7	6	4	5	3	20	2	1
8	19	15	16	18	17	11	14	13	12	9	8	20	21	10	6	7	5	4	3	2	22	23	1
9	23	3	18	17	19	15	14	16	13	12	11	20	21	10	9	7	8	6	4	5	22	2	1
10	10	11	12	13	14	15	16	17	18	19	20	21	22	9	8	7	6	5	4	3	23	2	1
11	13	12	11	10	9	8	14	15	16	17	18	19	23	20	7	6	5	4	3	2	22	21	1
12	9	10	11	12	13	14	15	16	17	18	19	23	22	20	8	7	6	5	4	3	21	2	1
13	11	9	10	12	13	14	17	15	16	19	18	21	22	20	6	7	8	5	2	1	23	3	4
14	14	12	13	11	17	15	16	18	19	20	21	22	10	9	8	7	5	6	4	3	23	1	2
15	15	13	14	12	11	16	17	18	19	20	21	22	23	10	9	8	7	3	6	4	5	2	1
16	14	10	13	12	11	15	16	17	18	19	20	22	21	8	9	7	6	7	4	3	21	2	1
17	11	10	12	13	14	16	15	17	18	19	20	21	22	9	8	7	6	5	4	3	23	2	1
18	10	7	8	11	13	12	14	15	16	17	18	23	21	19	9	6	5	4	3	2	22	20	3
19	12	11	10	13	14	15	16	17	18	19	20	21	9	8	7	5	6	4	3	2	22	23	1
20	13	14	10	9	8	11	12	15	16	17	18	23	19	7	6	5	4	3	2	1	21	20	22
21	9	10	11	12	13	14	15	16	17	18	19	23	22	20	8	7	6	5	4	3	21	2	1
22	15	10	11	14	13	12	16	17	18	19	20	23	21	9	7	8	6	5	4	3	22	2	1
23	16	17	18	14	10	15	11	12	13	21	19	23	20	9	8	7	6	5	4	3	22	2	1
Sum of ranks	333	279	305	324	308	296	334	341	354	356	354	495	464	287	158	169	166	136	84	112	473	156	66
Average rank	14.5	12.1	13.3	14.1	13.4	12.9	14.5	14.8	15.4	15.5	15.4	21.5	20.2	12.5	6.9	7.4	7.2	5.9	3.7	4.9	20.6	6.8	2.9

Thus, with respect to the pattern variability with time, the factor of wear of the printing screen has a perceptible effect on the parameter of color shade difference.

While estimating colors, in particular color differences in ceramic tiles, one should not forget some other important aspects, namely, physiological and psychophysical aspects [7]. In comparing these two aspects of color perception, the question arises: which color characteristics and in which order determine the observer's color preferences. A consumer perceives a color as a characteristic feature of the product itself or its package [7]. In other words, a consumer cannot always precisely estimate the color of the product. Furthermore, color preferences of a person depend on the techniques and principles of the person's perception and color differentiation: whether the person perceives color as a whole or pays attention to some specific features.

On the other hand, an important factor in color perception is the spectral composition of the illumination at the moment of viewing the product. Furthermore, the color of surrounding objects influences the color judgement due to the simultaneous color contrast phenomenon, while the colors seen prior to that moment influence one's color preferences due to the phenomenon of a consecutive color contrast [1]. Thus, perceived color differences correlate with subjective sets of color perceptions of each consumer. This suggests that the perception of the color of an object is three-dimensional [4] and, consequently, color perception can be correlated with the main psychophysical variables considered above: brightness, color saturation, and color tone.

To identify the correlation between instrumental analysis and subjective color perceptions of particular people, we organized an expert evaluation of color differences in a sampling of ceramic tiles previously measured. The experts were 23 persons with normal color vision [8]. The experiment was performed in the standard conditions (source C) [2 – 4]. Samples for evaluation were 23 ceramic tiles from an earlier studied tile batch taken after an interval of 500 tiles. In our experiment we were guided by the main principles of selecting experts, logical techniques and procedures used for analysis and summarizing of estimates obtained from a group of experts [9].

The method of the experiment was as follows. Each expert was asked to divide the presented samples into three groups differing in brightness, to have like samples in each group. The choice of brightness as the estimate criterion is related to the fact that according to many authors [7, 8, 10], color differentiability primarily depends on the difference of brightness parameters: the greater this difference, the easier the color can be differentiated.

The first group contained samples satisfying the following characteristics: the most saturated, the deepest; low brightness; a perceptible contrast between the pattern color and the background; a clear pattern. The second groups of samples satisfied the following characteristics: medium brightness, saturation, and deepness; contrast between the

background and the pattern less pronounced. The third group of samples satisfied the following characteristics: the lightest, non-saturated; contrast between the pattern and the background reduced, pattern blurred.

Each expert assigned ranks to the tested samples in the order of descending brightness starting with rank 1. Ranks 22 and 23 were assigned to the darkest samples, according to the experts' opinions. The results of ranking the tested samples are listed in Table 1. The table data were processed using the Statistika software package [11].

When comparing the average values of ranks assigned by experts to the tested samples it can be noted that samples from 1 to 11 have rather uniform values of this parameter; then the brightness increases perceptibly in samples from 14 to 20 and from 22 to 23. The fact that samples 12, 13, and 21 fall out of the general trend is related to the fact that before decorating these tiles technological breaks occurred on the silk-screen printing line, when the printing screens were washed with a water-moistened sponge and then wiped dry. Since more paste can be squeezed through a cleaned screen, the pattern on the tile seemed deeper.

The concordance between the expert opinions was estimated using the concordance coefficient [9], i.e., the total rank correlation coefficient for the group consisting of m experts. The concordance coefficient calculated based on the Kendall formula [9, 12] was equal to 0.63, which points to the nonrandom consistency between the opinions of the experts.

Although instrumental studies indicated that, as a consequence of plastic deformation and subsequent abusive wear of the polymer filaments of the printing screen, the brightness parameter first grows, then stabilizes, and finally smoothly decreases, consumers believe that starting at a certain moment the tile brightness increases. This is presumably due to the degree of contrast between the pattern color tone and the background. Considering that the color saturation of the tile has a general tendency to decrease with time as a consequence of the deformation of the screen filaments (Fig. 1), the degree of contrast between the pattern and the background decreases. Accordingly, the pattern is perceived as blurred and, therefore, the experts regard it as becoming lighter.

Thus, the reproduction of color today is one of the most difficult problems in the ceramic industry. Control and measuring instruments are almost never used in printing on ceramics. The color is controlled visually, i.e., a subjective or psychological estimate of colors is used, which depends on a number of color perception factors (brightness, color tone, and color saturation perception thresholds; lighting of the room; ambient color background, etc.). Since the difference between the perception of an individual person and the physical measurements is rather substantial, in order to use the instrumental methods in practice, it is necessary to find a way for converting the physical characteristics of colors obtained experimentally so as to have data comparable with color characteristics perceived by the consumer.

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